Cerenkov light production during proton therapy: simulation and experiment

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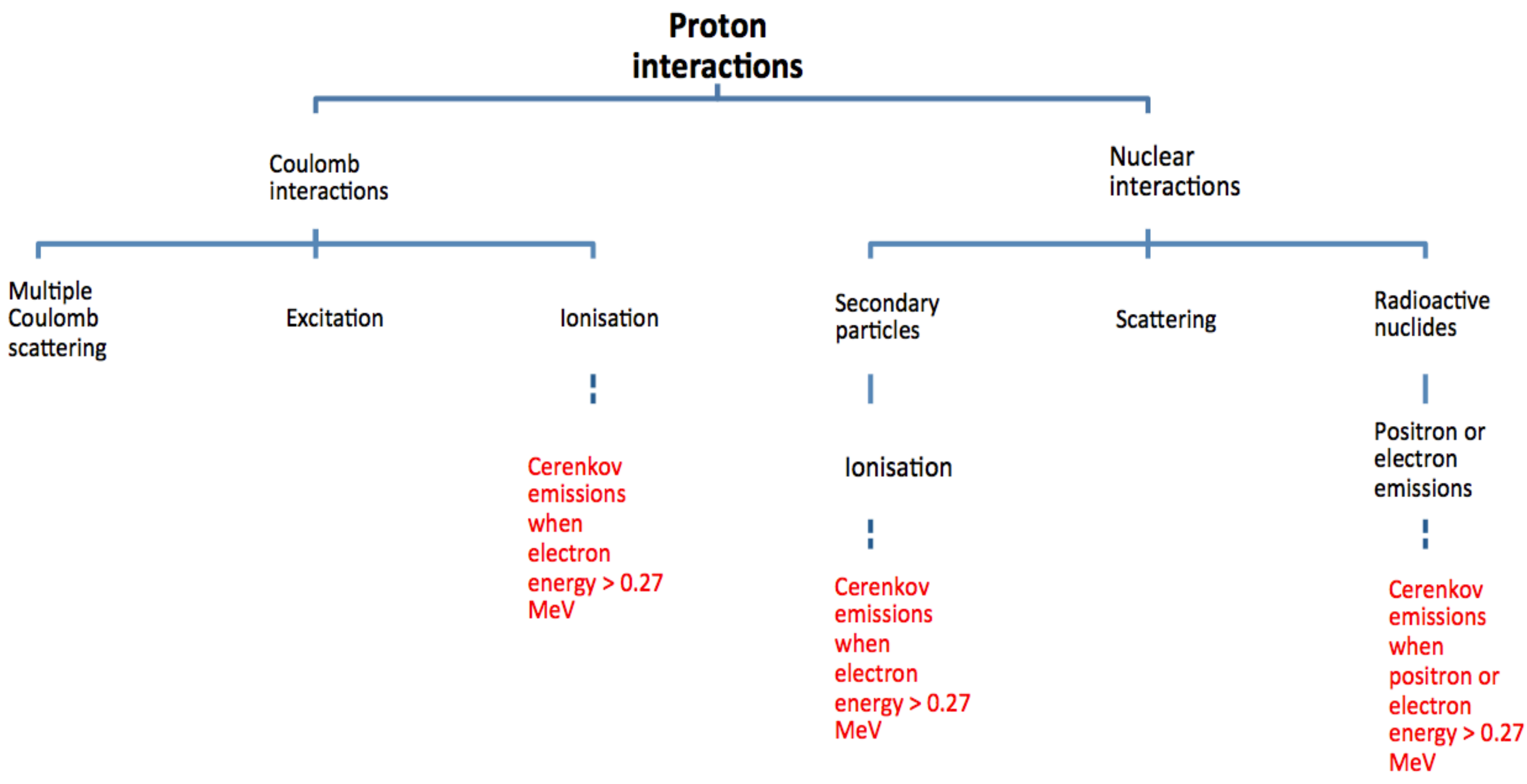
Motivation

Eye cancer patients frequently report a visual sensation during proton therapy. We investigated the possibility of Cerenkov emissions being behind it and explored using Cerenkov light for dosimetry and dose localisation in proton therapy.

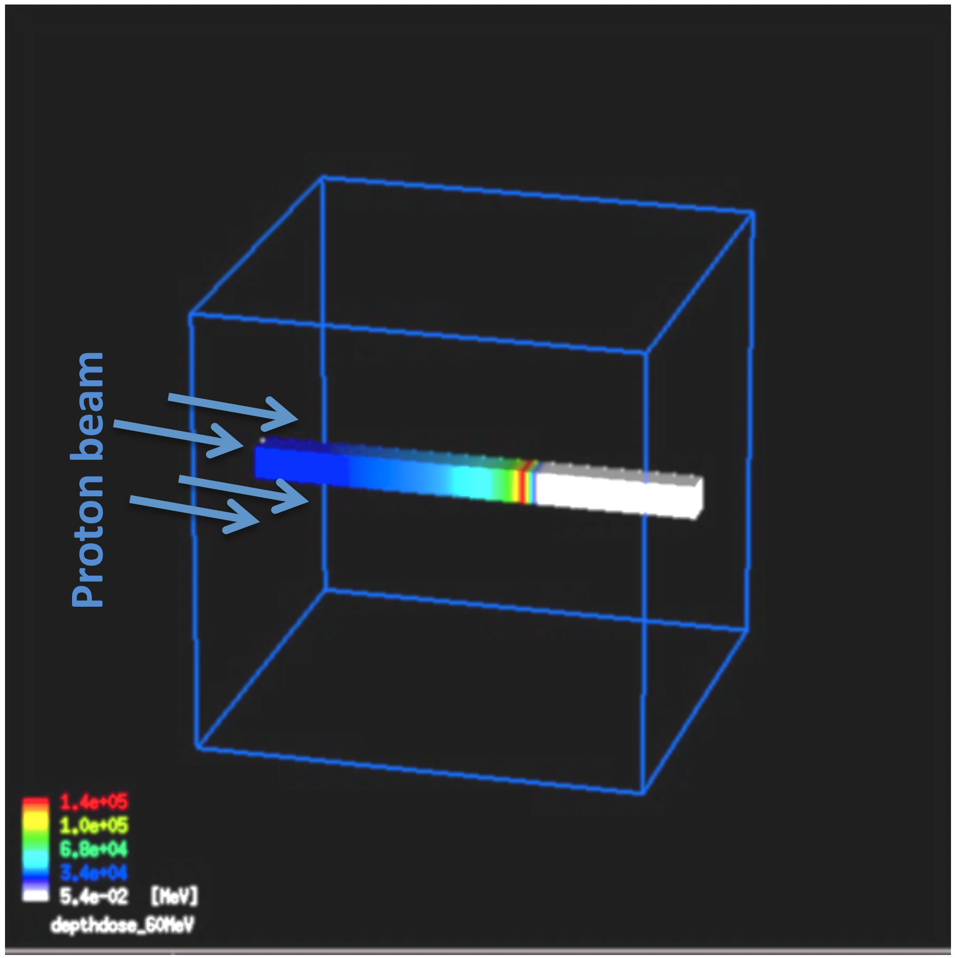
Possible explanation

- Nerve stimulation by proton beam.
- Scintillation
- Radioluminescence
- **Cerenkov radiation**

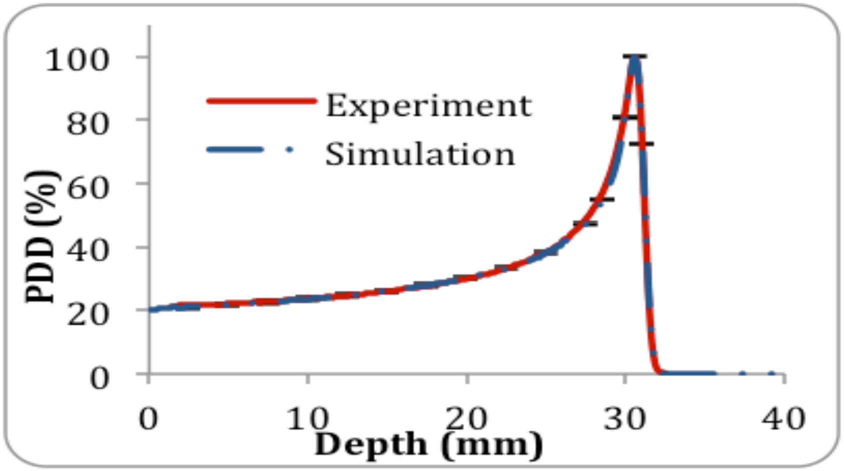
Proton interactions physics

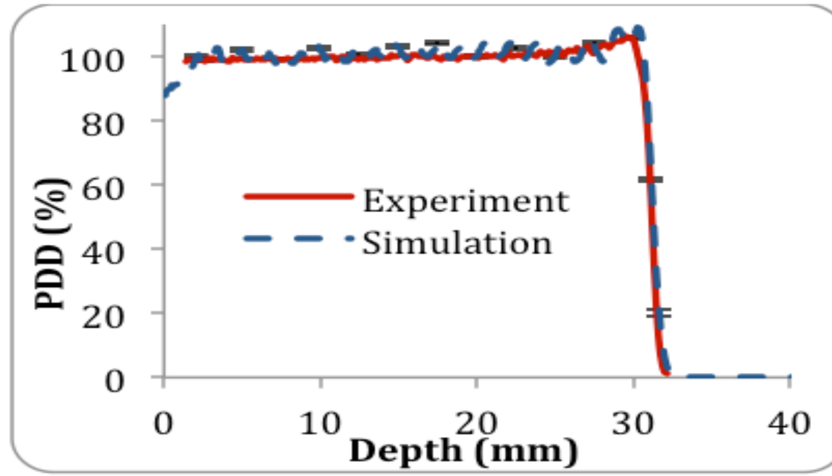


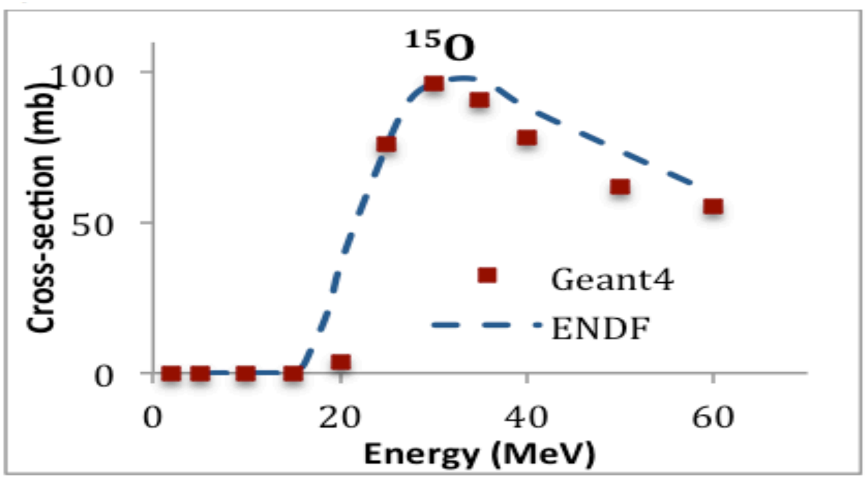
Proton beam simulation

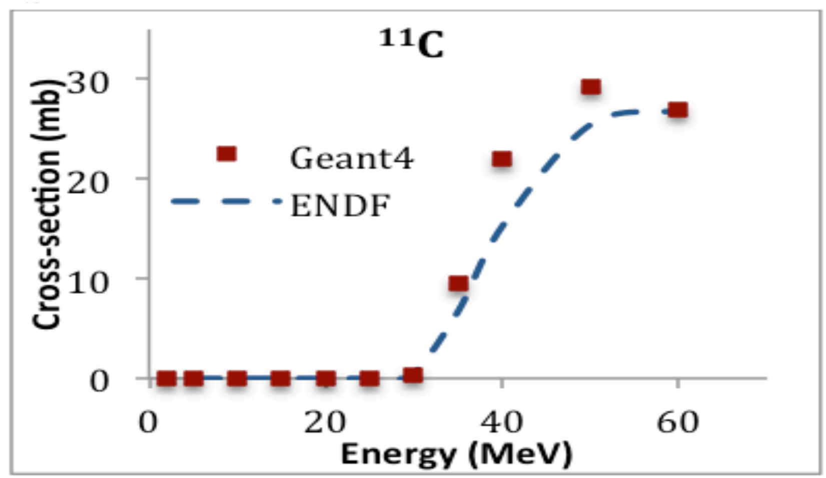


Code verification

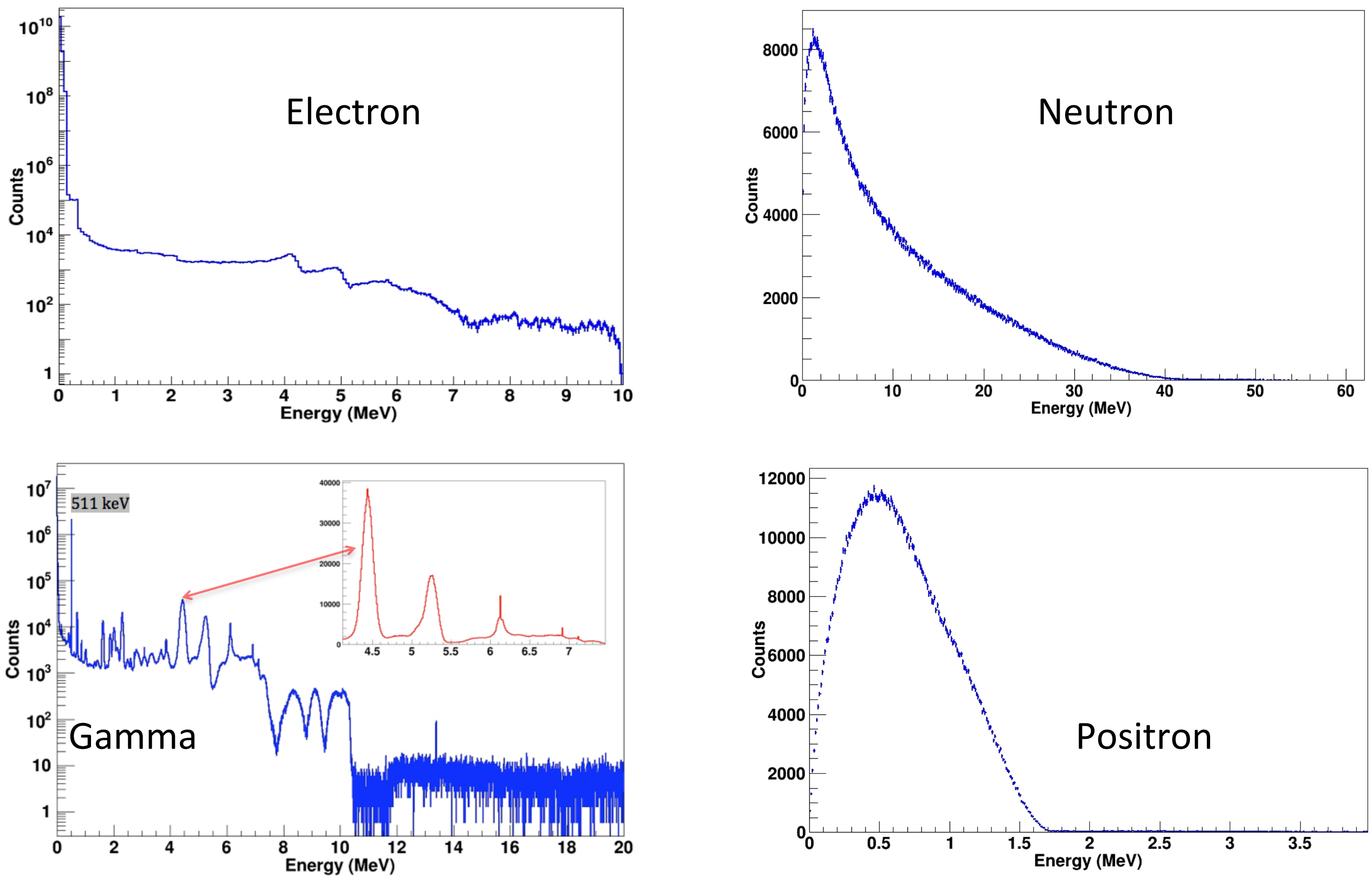








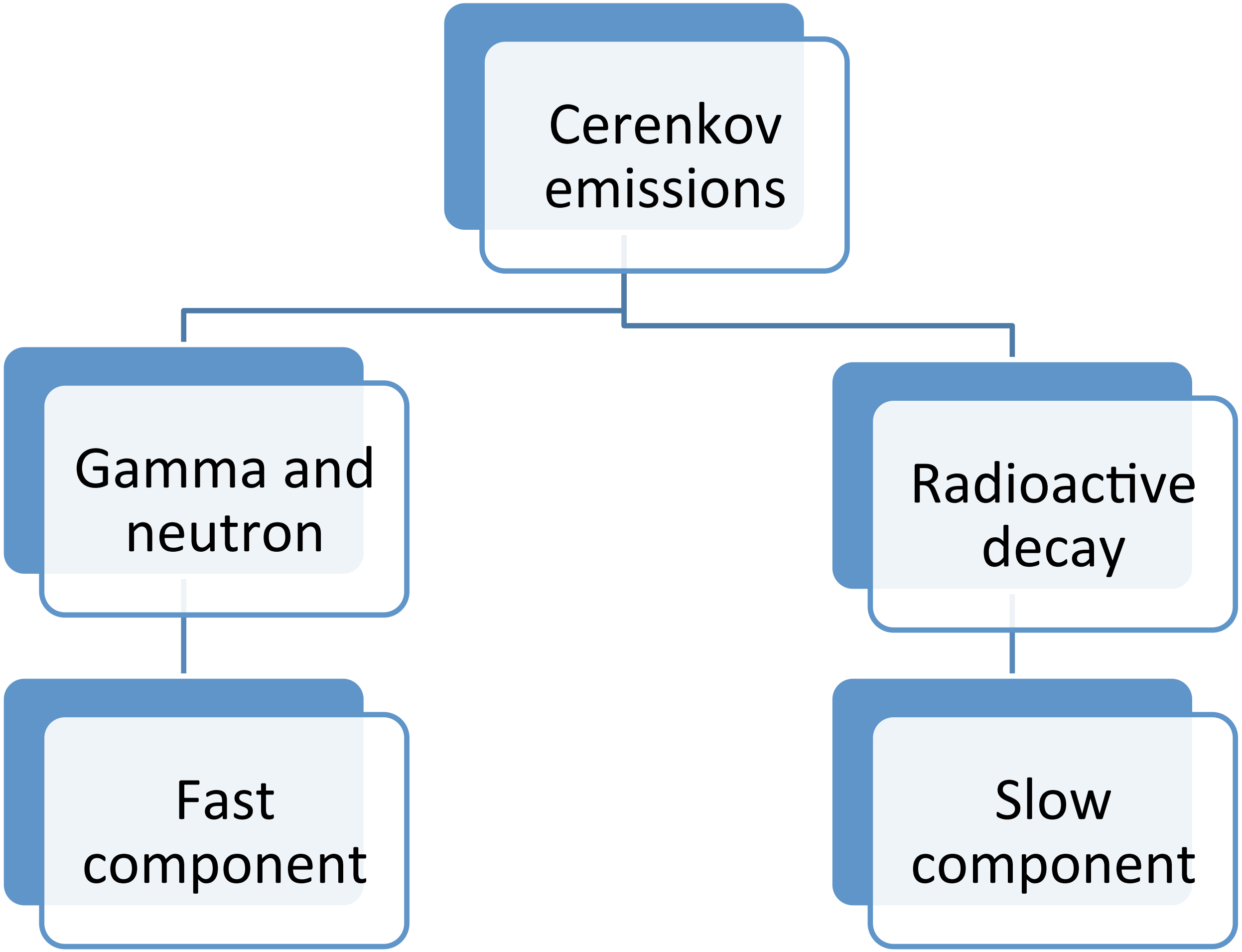
Secondary emissions
simulation used 10^8 protons



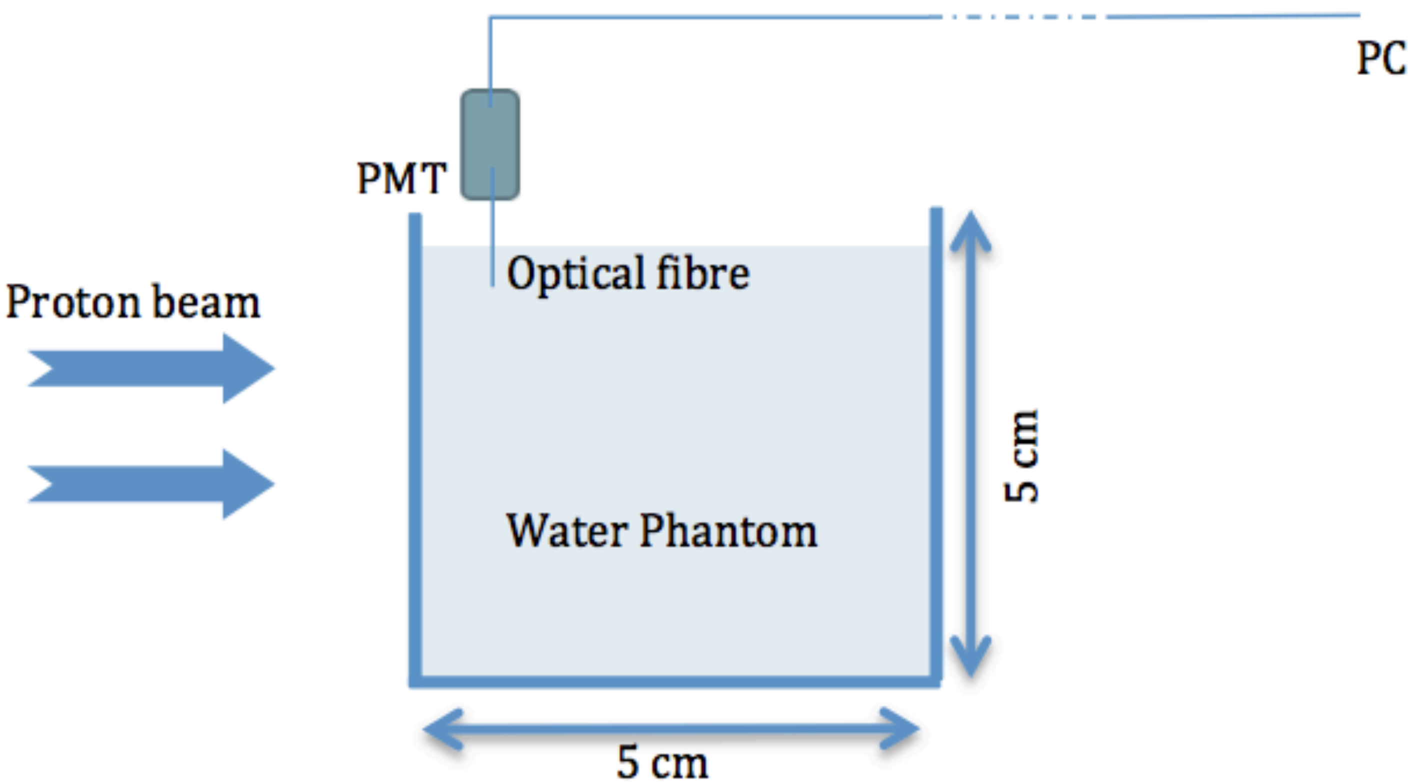
Most abundant radionuclides found in water after irradiation by 60 MeV proton beam

Nuclide symbol	Decay mode	Daughter	Half-life	Nuclides per 10^7 proton
^{15}O	**β^+**	**^{15}N**	**122.24 s**	**81164**
^{11}C	**β^+**	**^{11}B**	**20,33 min**	**23349**
^{13}N	β^+	^{13}C	9.96 min	1430
^{10}C	β^+	^{10}B	19.29 s	1320
^{14}C	β^-	^{14}N	5.73×10^3 year	980
^{14}O	β^+	^{14}N	70.598 s	630

Cerenkov production in proton therapy

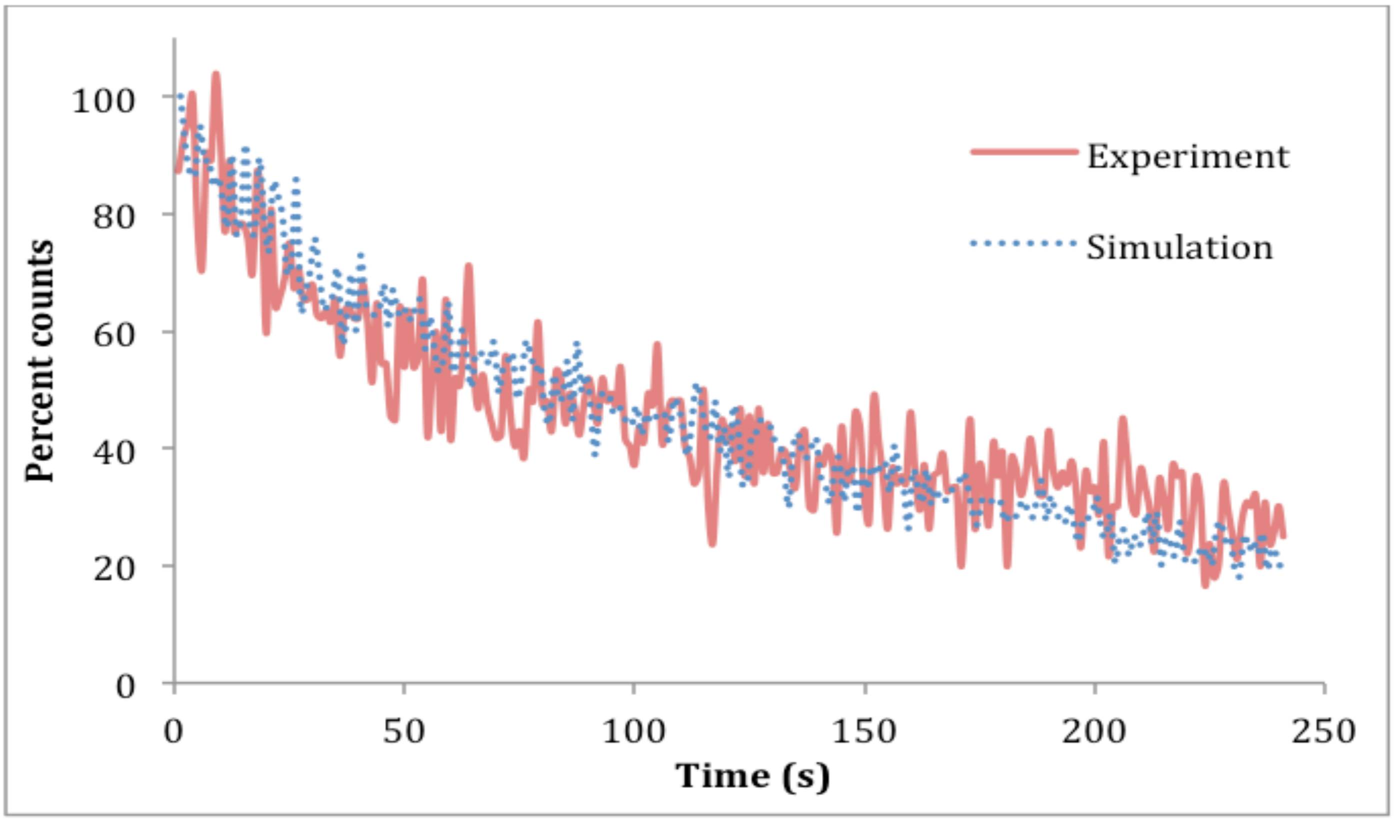


Proton experiment in 30/05/12



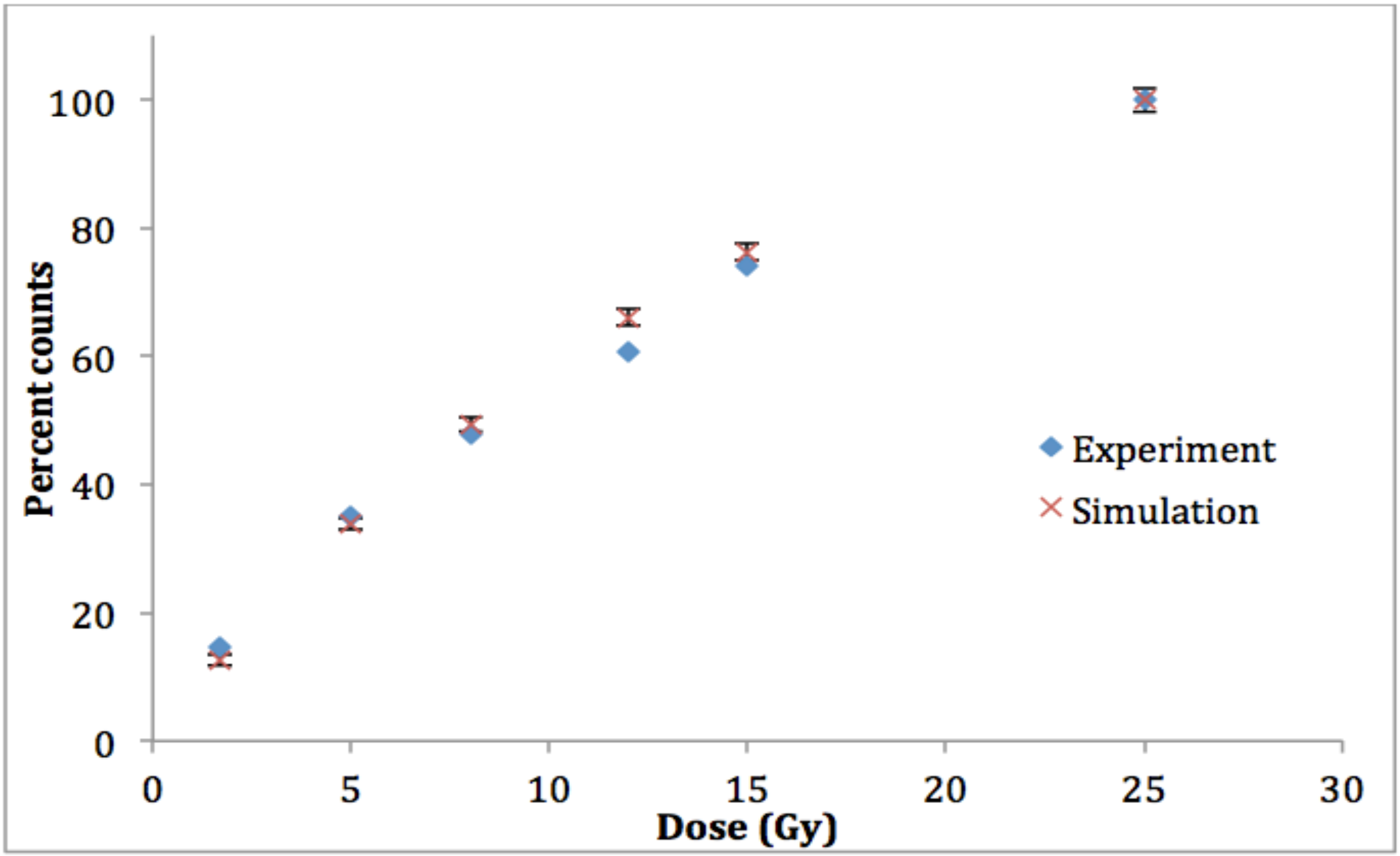
Cerenkov emission spectrum

Slow component

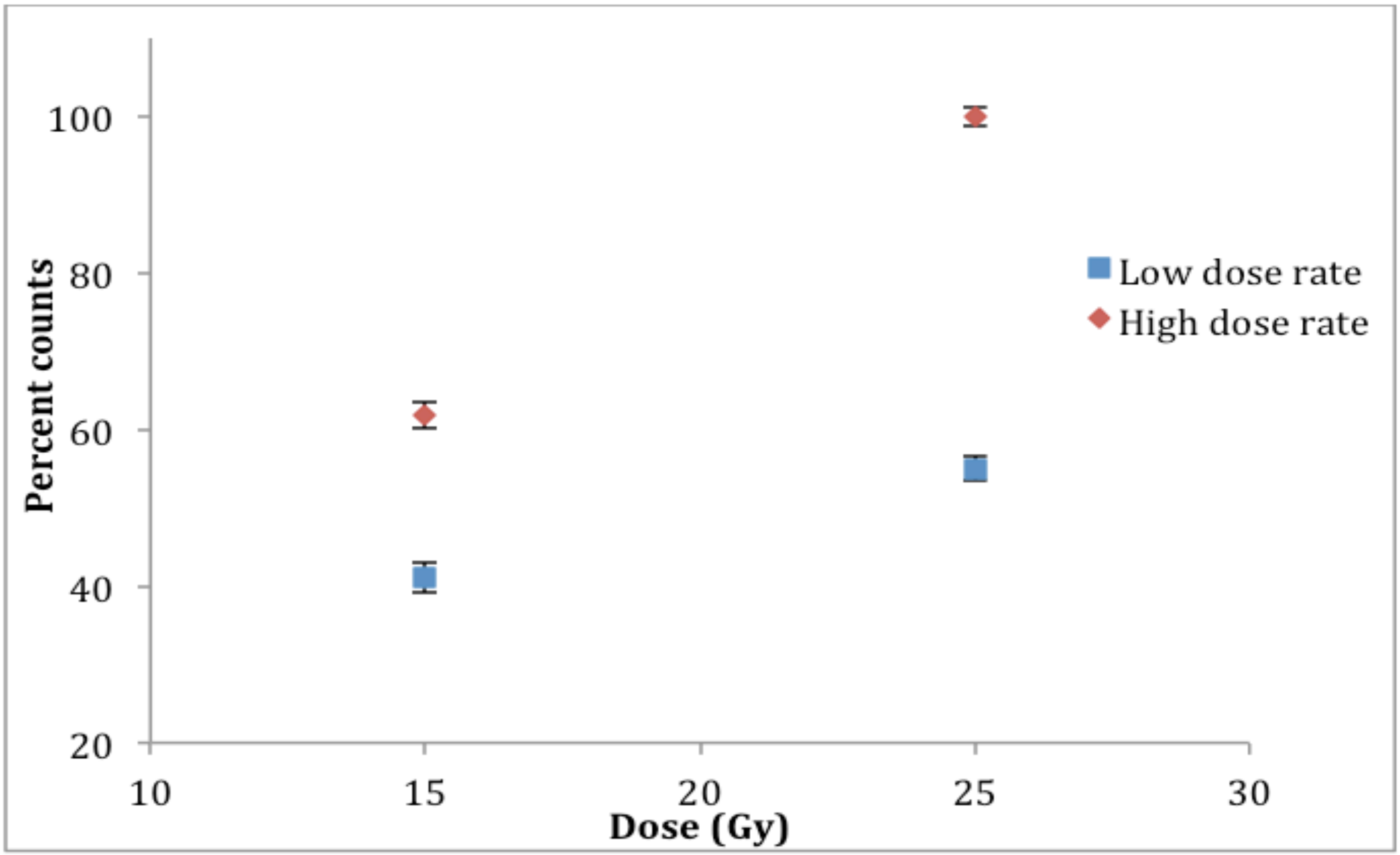


Helo, Y. et al., 2014. Cerenkov optical emissions in particle radiotherapy. in *Biomed. Opt. 2014* BM4A.6 (Optical Society of America, 2014) doi:10.1364/BIOMED.2014.BM4A.6

Dose linearity of the slow component

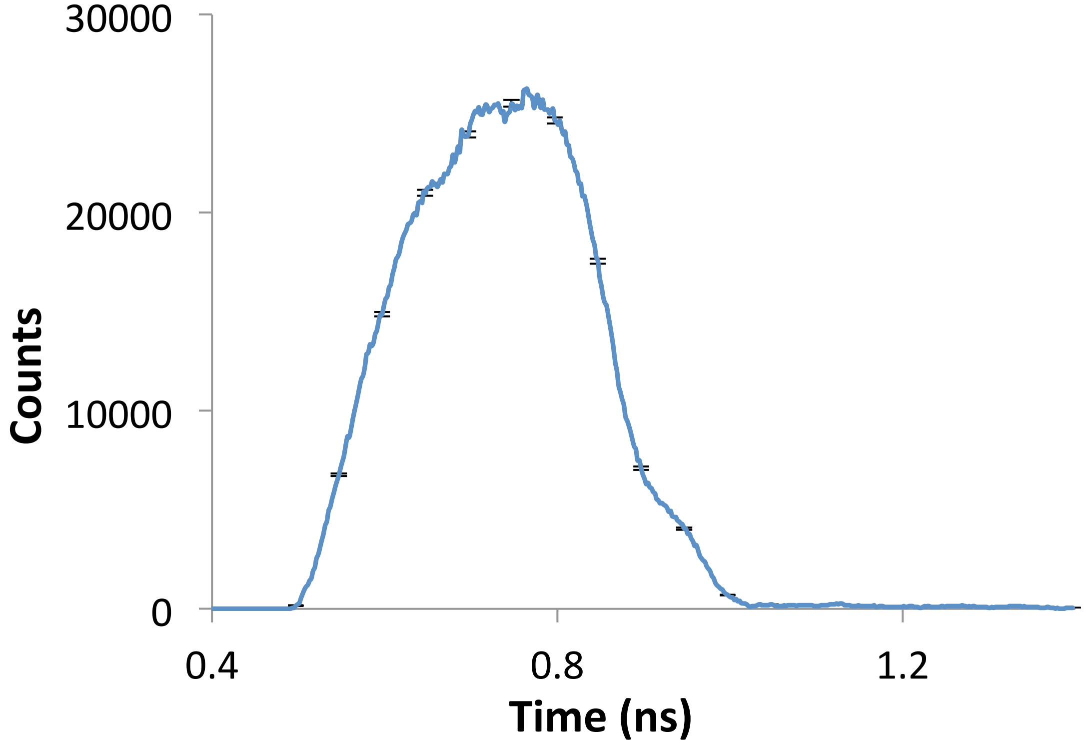


Dose rate dependency of the slow component



Cerenkov emission spectrum

Fast component



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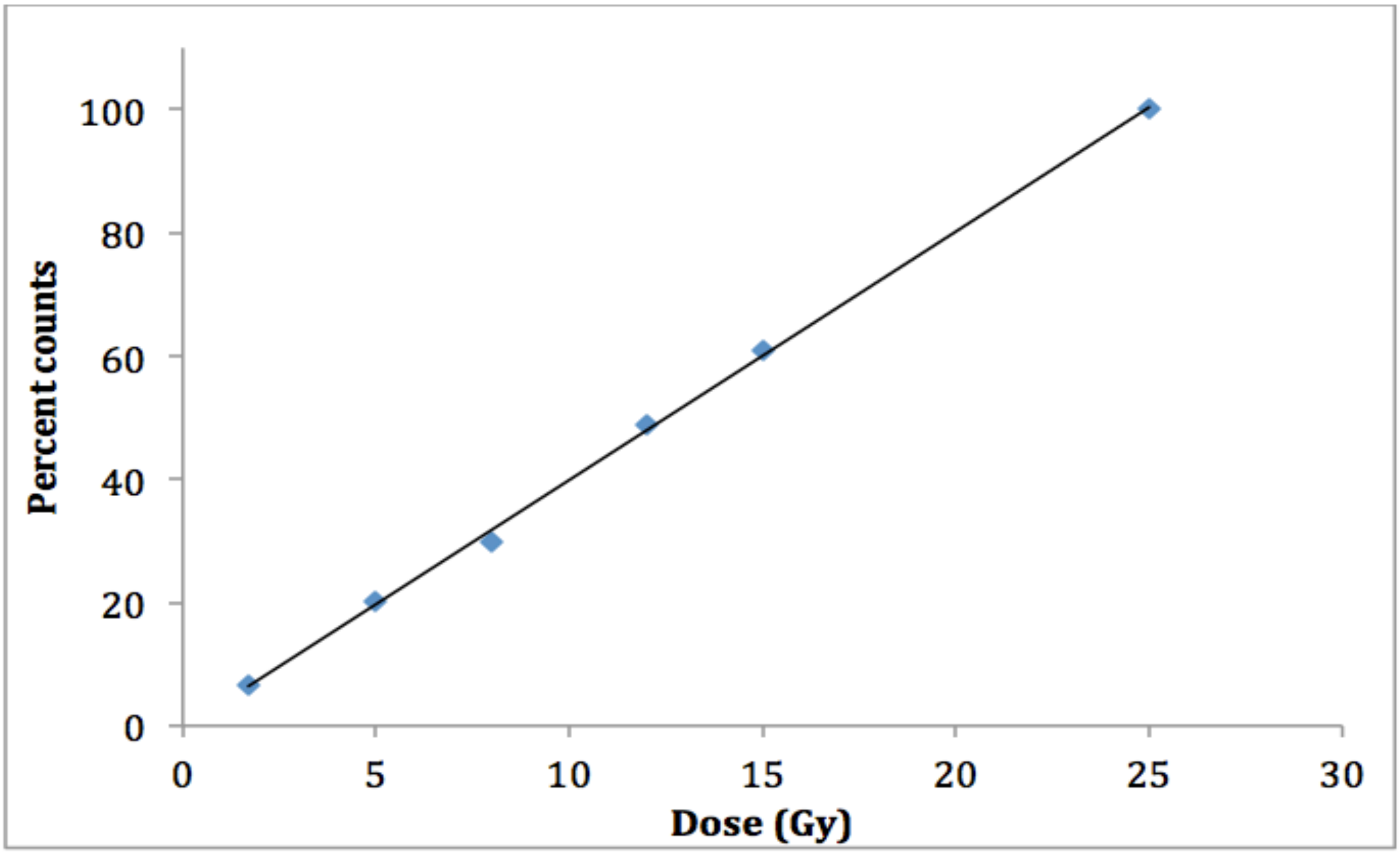
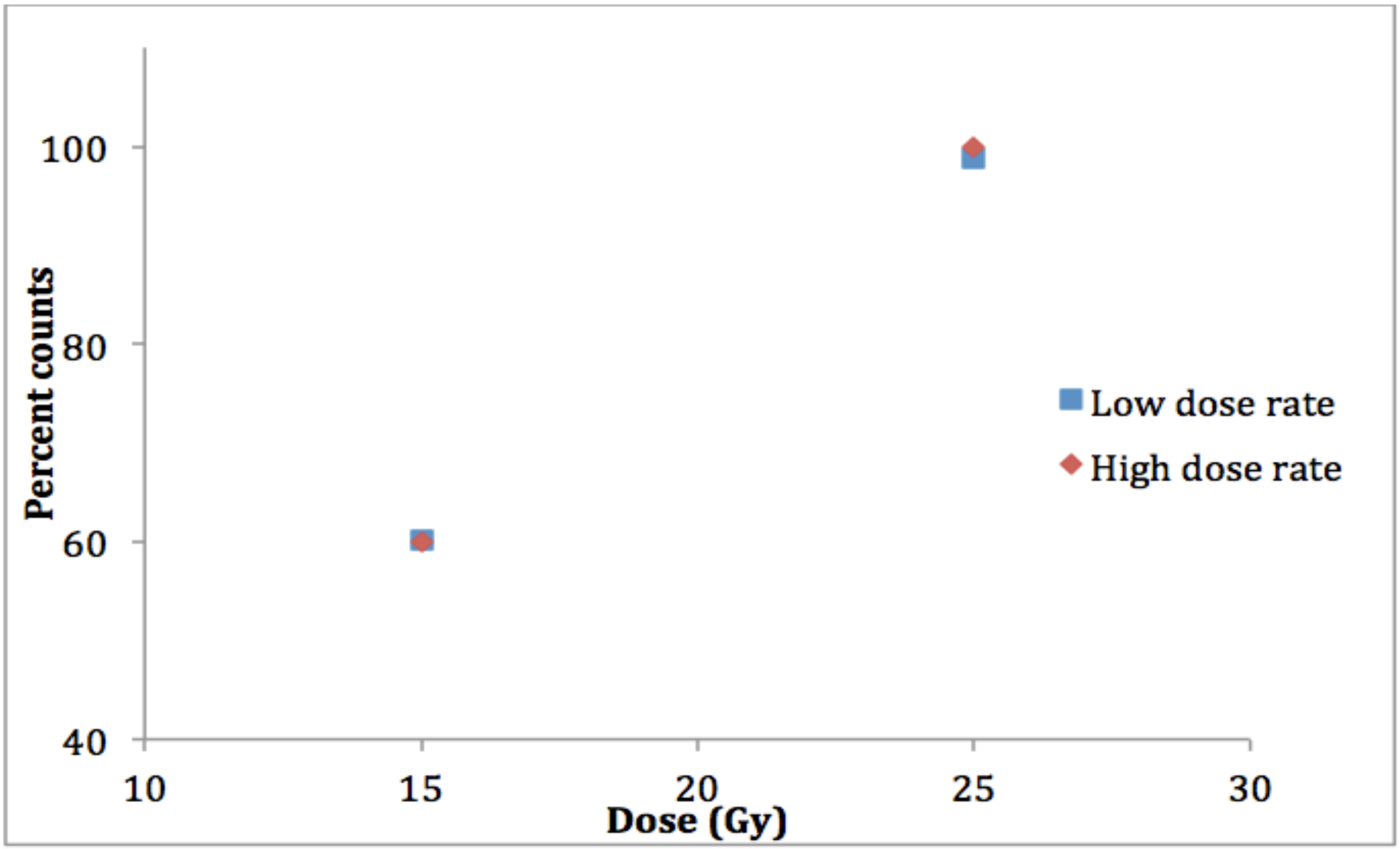
Dose linearity of the fast component



Dose rate dependency of the slow component



How many photons per second?

60 Gy in 4 fraction

30 – 60 seconds

$3 \times 10^8 - 2 \times 10^8$ protons per second considering eyeball weight 7.5 grams

The total number of generated photons inside the eyeball per second by the **FAST COMPONENT** is

1.3×10^8 photons per second

And by the **SLOW COMPONENT** is

from 0.6×10^6 to 1.6×10^7 photons per second

Conclusion

- Light emissions in proton therapy can be divided into fast and slow component.
- The fast component may explain the visual sensation seen during proton therapy treatment.
- Cerenkov images taken just after the treatment can be used as a depth verification in proton therapy.
- The fast component of Cerenkov emission in proton therapy found to be linear and independent to dose rate; While the slow component was found to be non-linear with dose and highly dose-rate dependent.

Previous work: Cerenkov production during electron therapy

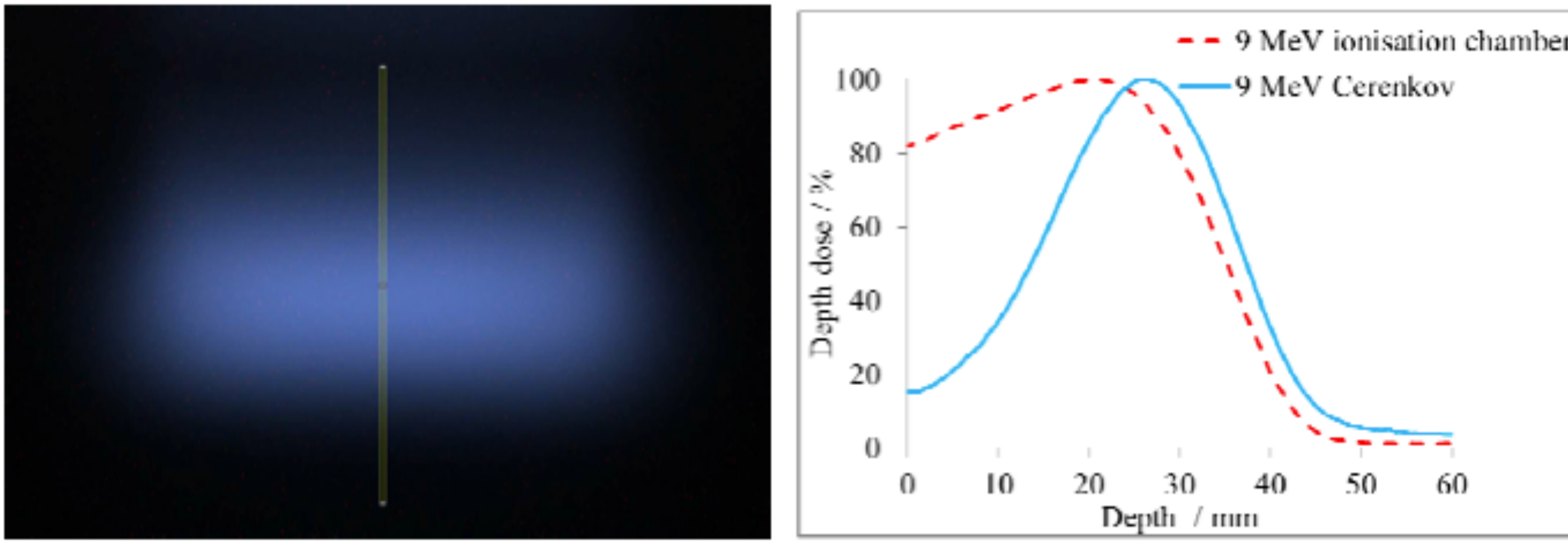


Fig 2: Photograph of Cerenkov emission from a 9 MeV electron beam (with the electrons being delivered from the top of the figure), and depth dose curves measured from a 9 MeV electron beam using an ionisation chamber and by extracting a profile from the Cerenkov image.

Helo, Y. et al., 2014. Imaging Cerenkov emission as a quality assurance tool in electron radiotherapy. *Physics in Medicine and Biology*, 59(8), p.1963.

Thank you